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In Situ Marine Sediment Probe and Coring Assembly

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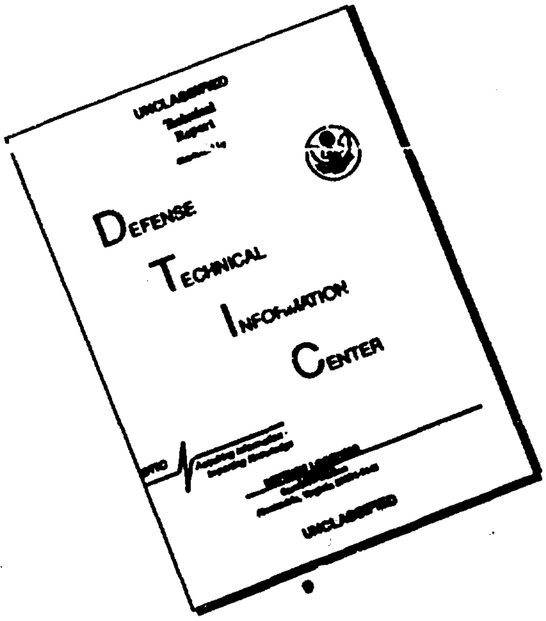

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ABSTRACT

A hydrostatically anchored four-probe assembly with a centrally located slow-penetrating corer measures the thermal and acoustic properties of sediments during incremental penetrations to 5 ft in water depths to 5000 ft. This deep ocean sediment probe can function from submersibles or surface vessels.

ADMINISTRATIVE INFORMATION

The study described in this report was performed under NUSL Project No. A-400-08-00-00, "Geological Oceanography Investigations" (U), Principal Investigator, J. J. Gallagher, NUSL Code 2213, and Navy Subproject and Task No. SR 104 03 01-12859, Program Manager, B. K. Couper, NAVSHIPS 00V1.

This is the final report for work completed at the University of Rhode Island Soil Mechanics Laboratory under NUSL Contract No. N00140-69C-0078. Originally, this manuscript was prepared for and presented at a meeting of the American Society of Civil Engineers and the University of Miami. The meeting was held in Miami, Fla., from 10 to 12 December 1969.

The Technical Reviewer for this report was Kirk Patton, of the Marine Technology Branch, Ocean Sciences Division.

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INTRODUCTION

The degree of disturbance affecting the in situ sediment structure during standard core sampling and the alteration of the aggregate properties of the sediment as the core is elevated to the surface are problems that have vexed oceanographers for many years.[1-7] These problems introduce an unknown quantity in evaluating in situ acoustic propagation and engineering strength behavior in high porosity marine sediments and also in describing highly accurate interrelationships between the acoustic, geotechnical, and mass physical properties of the sediment-water aggregate.[7-11]

The required resolution of these problems led marine scientists to a continuing search for improved ideas, instrumentation, and techniques. Attention was directed to progress in petroleum exploration, in particular, the field of well logging, where many of the parameters measured and the environmental conditions encountered are similar to those in marine science and where large sums of money have already been expended to achieve a rather advanced state of instrumentation development. Adaptations of well logging equipment for marine sediment investigations have been described.[3, 12-14] Some unique sediment in situ instrumentation also has been developed within the oceanographic community.[15-23] Although all present oceanographic in situ instrumentation developments are indirectly applicable to the study of the in situ acoustic properties of marine sediments, no direct acoustic measurements, relationships, or correlations are being attempted. Also, none of the present efforts has the capability of collecting a high quality core sample at the specific site of in situ penetration for direct comparisons of in situ and core sample data.

The research reported here discusses a single platform for determining properties in situ and obtaining an "undisturbed" sediment sample on which to make correlative laboratory measurements. Major goals of this investigation are to evaluate the degree of disturbance in sampling and to confirm the validity of careful in situ tests.

DEEP OCEAN SEDIMENT PROBE

The Deep Ocean Sediment Probe (DOSP), Fig. 1, was designed by the University of Rhode Island (URI) for the Navy Underwater Sound Laboratory (NUSL). The Atkins and Merrill Corp., Engineering Model and Mockup Division, of Sudbury, Mass., assisted in the design of the platform and also fabricated the main structure. After URI installed the electrical components and completed the construction, the DOSP was delivered to NUSL in February 1969. The objective of the device is to obtain in situ values of acoustic, geotechnical, and geochemical properties of marine sediments. At present, the active and passive transducer components consist of a capacitive discharge spark acoustic source, hydrophones, and thermistors.

An electric motor operates a mechanical system that drives four probes incrementally and without rotation into the sediment to a maximum depth of 5 ft, and then a centrally located, thin-walled corer is driven continuously without rotation to the same depth. An automotive sparkplug in one probe tip provides the source of acoustic energy that is sensed by hydrophones at distances of 4 and 6 ft in the other three probe tips. Because of the fast rise time, the high energy at the high frequency, and the waveform characteristics at the beginning of the received acoustic pulse, an accurate value of the in situ sound velocity in the sediment can be determined. This parameter is also determined under triaxial compression in the laboratory on small samples taken from the undisturbed core and from standard cores to determine relative degrees of disturbance in the particle aggregate structure and the influence of this disturbance on the value of sound velocity. Investigations of attenuation of the broad-band acoustic signal are also being undertaken, and a thermistor on one probe senses sediment temperatures for use in sound propagation studies.

The DOSP was designed primarily for use with deep submersible research vehicles (DRV's) and secondarily for use from surface vessels. However, DRV funding and certification restrictions within the Department of the Navy have forced a reversal in this primary utilization.

Initially, the entire probe assembly was field tested in February 1969 from the USNS SANDS (T-AGOR-6) in shallow water off Puerto Rico. The results of the shipboard handling, penetration, and data acquisition trials were highly satisfactory. Additional tests were performed in August and October 1969 from the University of Connecticut's R/V UCONN in shallow water off the

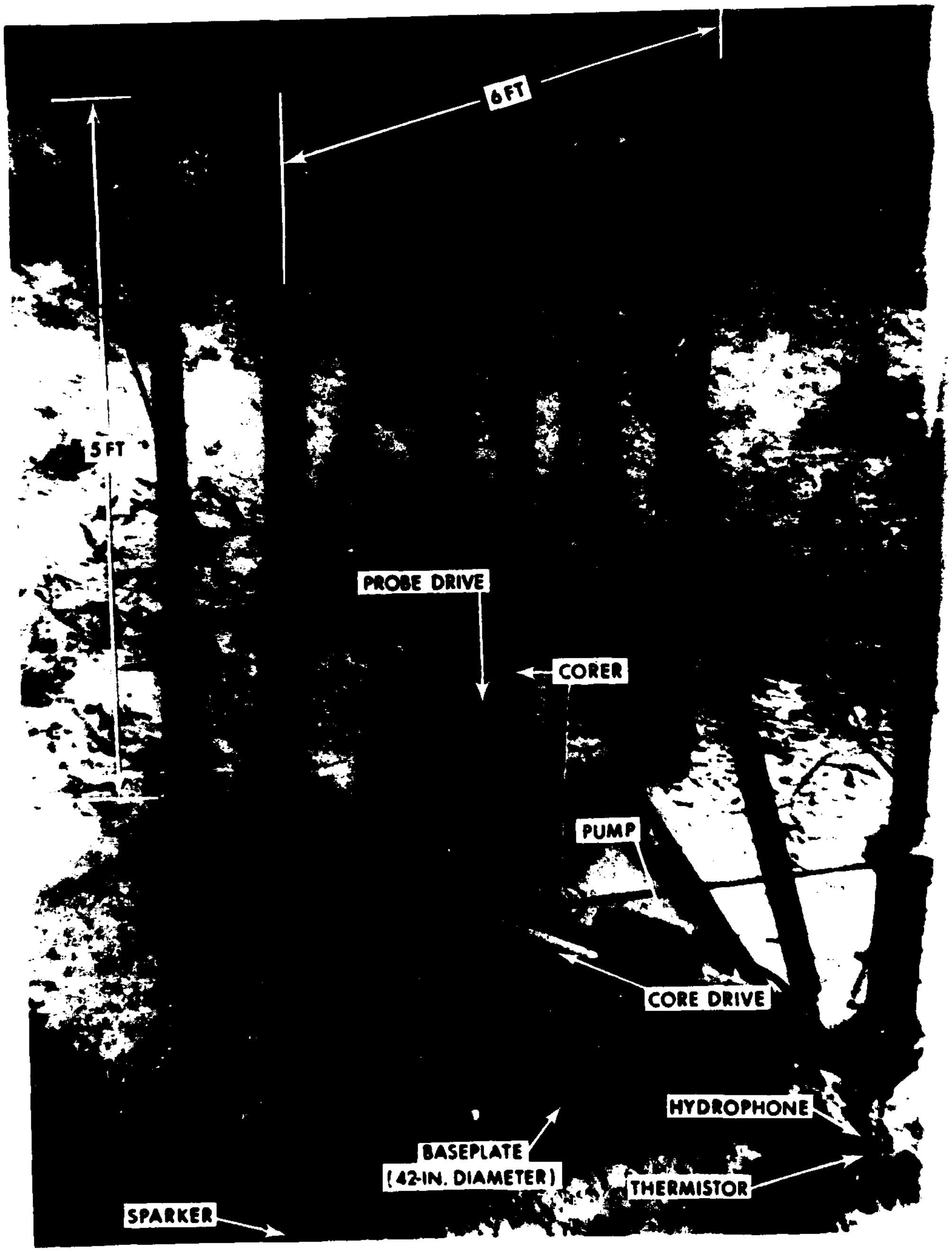

Fig. 1 - Deep Ocean Sediment Probe (DOSP)

Connecticut and Rhode Island coast. The DOSP was tested in a range of coarse shelf sediments, and these tests have led to some structural changes and an increased anchoring capacity of the DOSP. The acoustic system functioned reliably, and records from these tests are presently being analyzed at URI.

During the latter tests, scuba divers were employed to take compass readings and measure distances (less than 40 ft) between stations to enable the DOSP to obtain cores oriented with respect to each other and magnetic north. This work was undertaken as part of a local shelf sediment study by investigators of the URI Narragansett Marine Laboratory.

DESIGN DESCRIPTION OF THE PROBE

DIMENSIONS AND WEIGHTS

The primary dimensions of the DOSP and the weights of the electrical components are presented in Fig. 1 and Table 1, respectively. The total structure including electrical components (motors, pump, spark source, etc.) weighs approximately 350 lb in water and 550 lb in air.

PENETRATION

The system is designed to achieve penetrations of 5 ft. According to the experience of others,[16] this penetration is a practical one for DRV work. The range of shear strength of most deep sea sediments to this depth is from 0.05 to 5.00 psi.[22] The baseplate has been equipped with a suction pump (Benthos, Inc., Model 2090-17) in order to provide the necessary static weight for penetration into the low-strength soils. When the pump is run in reverse, it is useful also in reducing the breakout force. The present system accommodates four corner probes and a corer. The corer is situated in the central sector so that a representative sample of the sediment can be obtained. The sample is taken after the acoustic measurements are completed. A worm gear is turned by a 1/2-hp electric motor to drive a chain that rotates two jackscrews in such a way that a threaded cap attached to the corer moves along the screws. For the four probes, another 1/2-hp motor drives a gear attached to a chain that rotates threaded sleeves. These sleeves drive screw assemblies at the top of each probe and, thereby, force the probes into the sediment. The probes are lowered simultaneously, without rotation, at a rate determined by the chain speed and sediment resistance.

Table 1
ELECTRICAL COMPONENTS OF THE DEEP OCEAN SEDIMENT PROBE

System	Component	Number	Weight Aboard the DOSP (lb)	Weight Aboard the Support Vehicle (lb)	Power (W)
Acoustical	Spark Source	1	1	5	50(a)
	Hydrophones	3	2		0
	Filters	3		50	0
	Amplifiers	3		20	10(a)
	Oscilloscope	1		50	200(a)
	Tape Recorder	1		100	200(a)
	Velocimeter	1	20		5(c)
	Digital Frequency Counter	1		20	20(a)
Temperature	Thermistors	2	0		0
	Digital Ohmmeter	1		20	20(a)
Drive Motor	Motors	2	60		500(b)
	Gear Boxes	2	20		0
	Suction Pump	1	10		120(c)
	Inclinometers	2	0		0
			112 (total)	260 (total)	

Notes for power requirements:

(a) = 110 V, single-phase ac = 500 W

(b) = 220 V, three-phase ac = 500 W

(c) = 12 Vdc = 125 W

Magnetic switches (Benthos, Inc., Model 2221) on the DOSP interrupt command signals and, thereby, actuate bottom-mounted relays so that the power to the drive motors is turned off at a preset limit of travel for both the probes and the corer.

Two ±15 pendulous potentiometers (Edcliff Instruments, Model 5-150), mounted at right angles to each other on the DOSP, serve as inclinometers. By monitoring the electrical resistance of these pendulums on a digital ohmmeter (Hewlett Packard, Model 3444A), the operator can determine the vector of tilt due to water current or to difficulty in probe or core penetration in coarse sediment.

A 3-A ammeter placed in series with the ac power line from the generator serves to indicate the degree of loading on the drive motors; the degree of loading also is indicative of the degree of difficulty in penetrating coarse sediment.

ACOUSTIC INSTRUMENTATION

The acoustic source is a "sparker" type capacitive discharge device[21] with an automotive sparkplug as the electrode; the intensity of the spark is 20 J. Figures 2 and 3 show the entire sparker assembly, including the power supply, capacitive discharge electronics, pressure case, control unit, and probe housing. The three hydrophones are piezoelectric blast-type hydrophones (NUSL Model XU-1385). Acoustic signals in the frequency band 1-80 kHz are received, amplified (Ithaco, Model 253-A), and recorded on a shipboard tape recorder (Precision Instrument, Model PS 207A). Shipboard noise is filtered out below 1 kHz (Allison Laboratories, Bandpass Filter Model 2ARW).

The reliability of this sparker acoustic source has been confirmed in a series of tests. The first tests consisted of firings in an NUSL fresh water pressure tank to ambient pressures of 5000 psi. A current density in the sparkplug gap of sufficient magnitude to cause vaporization of the medium demands a 30 to 50 percent higher potential in fresh water than in salt water. Thus, the success of these tests indicates the ability of the sparker, in its present configuration, to fire easily at ambient pressures well in excess of 5000 psi in salt water. This conclusion was satisfied by subsequent salt water firings to 5000 psi at the URI.

Figures 4A and 4B show the acoustic waveform of the spark source in fresh water. The fast rise time, the high energy at the high frequency, and the waveform characteristic at the beginning of the pulse help to determine

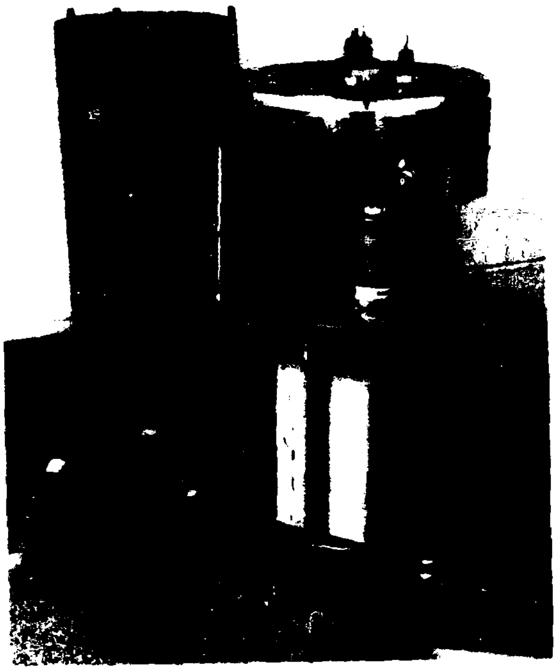

Fig. 2 - Sparker Power Supply, Control, and Pressure Case

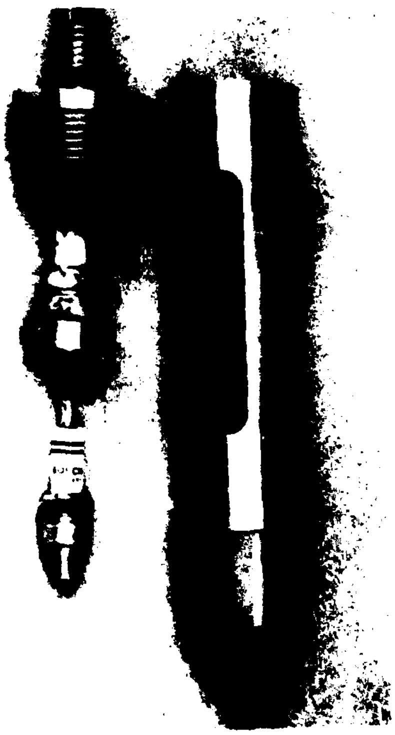

Fig. 3 - Sparker Probe

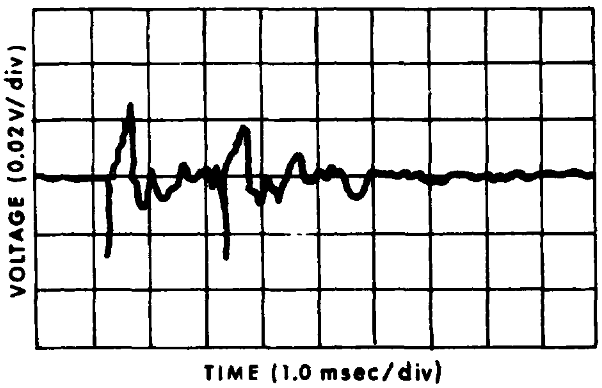

Fig. 4A - Spark Discharge (Total Signal)

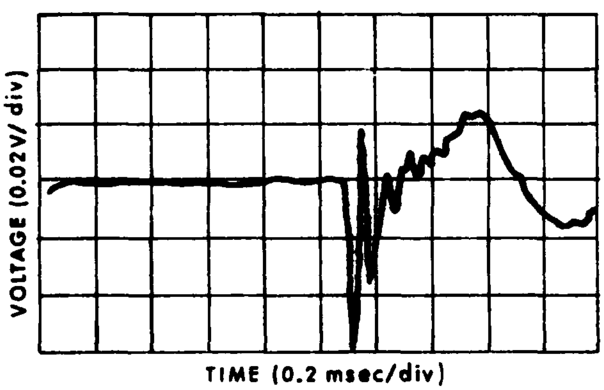

Fig. 4B - Spark Discharge (Leading Edge Expanded)

Fig. 4 - Spark Discharge

accurately and repeatedly the time of arrival. The output waveform of the pulse is quite repeatable.

A block diagram of the acoustic system is shown in Fig. 5. As the result of a recent modification, a dc pulse is sent simultaneously as a reference time mark to one channel of the tape recorder and as a trigger pulse to the sparker. The time delay between the current drain at the sparkplug and the initiation of the dc pulse is a constant 3.8 μsec. The hydrophone signals are sent at low impedance (by means of balance impedance transformers) on shielded wire pairs to the ship where they are filtered, amplified, and recorded on three of the tape recorder channels. Two other tape channels are used for audio information and a reference tone (Hewlett-Packard Oscillator, Model 200 CDR). The latter is used to correct for amplitude and tape speed variations when data are analyzed.

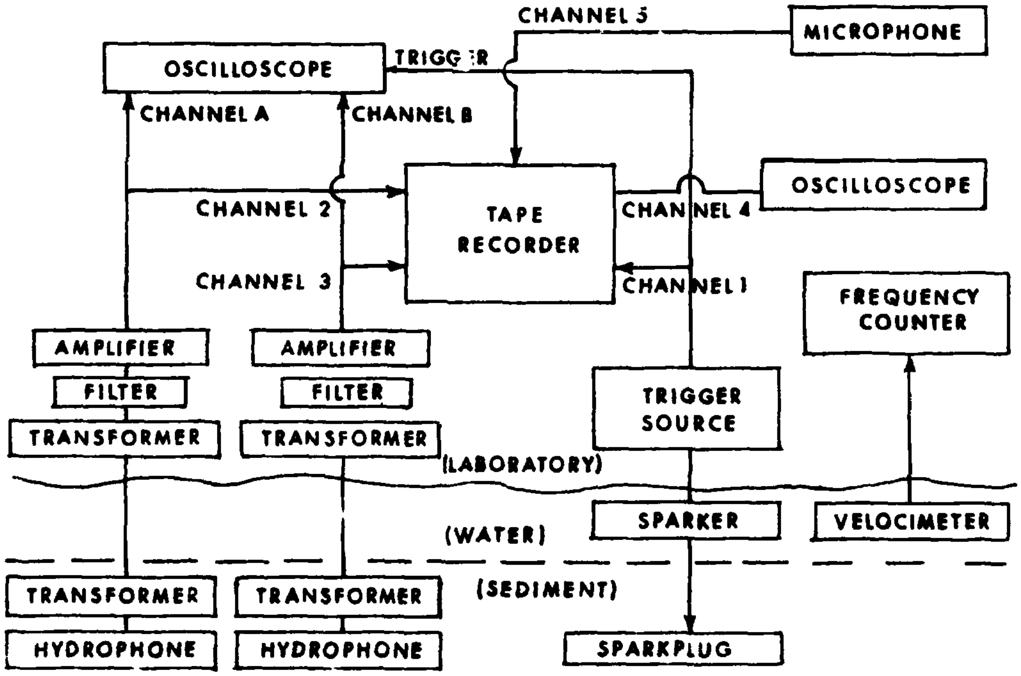

Fig. 5 - Block Diagram of Acoustic System

The sound speed in water is obtained from a sound velocimeter (NUS Corp., Model 1030-101) and is recorded on a counter/printer or read off a digital frequency counter (Hewlett-Packard, Model 5512A) and recorded on the audio tape channel. The system is calibrated in the field by means of a dual-channel oscilloscope (Tektronix, Model 561A with Model 3A1 amplifier and Model 3B3 delay time base).

THERMAL INSTRUMENTATION

A Fenwal Electric "Iso-Curve" bead thermistor, located in the tip of one of the probes, indicates the in situ temperature. This resistance value is read at levels in the sediment where acoustic measurements are made. The resistance is indicated on a digital ohmmeter and is recorded verbally on an audio tape channel.

CABLE AND CONNECTORS

A summation of the present power requirements for each of the electrical components appears in Table 1. A 12-Vdc relay system reduces the number of power and command conductors for the sparker, the drive motors, and the pump; however, as shown in Table 2, many conductors are still required.

The hydrophone and thermistor conductors must be either shielded pairs or coaxial, and the power conductors must be at least 12 AWG to limit resistive losses. In surface ship operations, dc power is provided by bottom-mounted, pressure-compensated automotive batteries, and two of the conductors can be eliminated.

The DOSP is currently being modified for use in deep water from a surface ship. At present, it can be used from a DRV without modification, but the number of conductors and ac power losses limit its use with long cables. Design changes include the substitution of dc motors and power supply on the DOSP with switching control aboard the support vehicle. Also, all sensors and function commands will feed into an FM multiplex system so that all data will be fed through a single conductor pair. With these changes, the DOSP will be able to operate from surface ships in water depths to 5000 ft by using a six-conductor strength member cable.

Table 2
ELECTRICAL CONDUCTORS

Function	Number of Conductors	Component
Data	3	Hydrophones
	1	Thermistor
	3	Inclinometers
	1	Velocimeter
Command	1	Corer
	1	Probes
	1	Pump
	1	Sparker
Power	4	Power Supply - ac
	2	Power Supply - dc

FIELD TEST RESULTS

The DOSP was tested successfully from the USNS SANDS (T-AGOR-6) in February 1969. Personnel from URI and NUSL cooperated in testing the probe in 55 ft of water in Mayaguez Bay, Puerto Rico. For this initial trial, divers and underwater television were used in order to learn as much as possible about the performance of the DOSP.

In a typical penetration sequence, the DOSP was lowered to the bottom; the hydrostatic anchor pump was actuated to reduce the pressure beneath the base skirt and, thereby, obtain a holding force; the probes were driven incrementally into the sediment to make acoustic and thermal measurements; and then the corer was driven slowly and continuously into the previously insonified portion of the sediment. During the retrieval operation the corer and probes were retracted sequentially, the anchor pump was reversed to reduce the suction below the skirted base, and the DOSP was winched off the bottom. Penetration distances and rates were determined by checking the reference marks on the corer by means of the shipboard video monitor and a buoyed line attached to one probe. Underwater television coverage was provided by a Hydro Products

TV camera held by a diver. The average rates of penetration over 8 casts were 48 sec/ft for the probes and 39 sec/ft for the corer.

A failure in the firing capacitor during pretest shipboard checkout prevented the use of the sparker as an acoustic source during these tests. A 12-kHz Depth Telemetering Pinger (Remaco, Model 1066X) was substituted as the acoustic source. Divers inserted the pinger approximately 2 ft into the sediment at a distance of 6 ft from the DOSP and on a line with two diagonally opposite legs, each containing a hydrophone (NUSL, Model XU-1385). The triggering time of the battery operated pinger was obtained by attaching a hydrophone (Gulton Industries, Model SSQ-23) near the pinger driving head. All three received signals, a reference tone, and audio instructions were recorded at 30 in./sec on a magnetic tape recorder. These tapes were replayed in the laboratory at 7-1/2 in./sec on a Sanborn/Ampex tape recorder (Model 2000) and into a filtered delay generator system, as shown in Fig. 6. Arrival time differences between hydrophones were determined from the digital counter display (Hewlett-Packard, Model 52452) and oscilloscope photographs (Figs. 7A and 7B). These time differences were then corrected for tape recorder playback speed differences before the sound velocities were calculated.

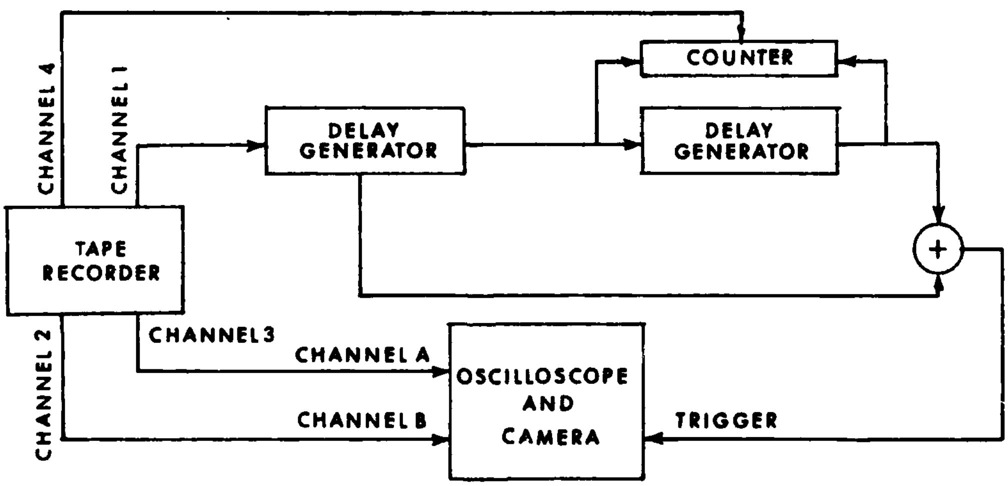

Fig. 6 - Block Diagram of Laboratory Playback System

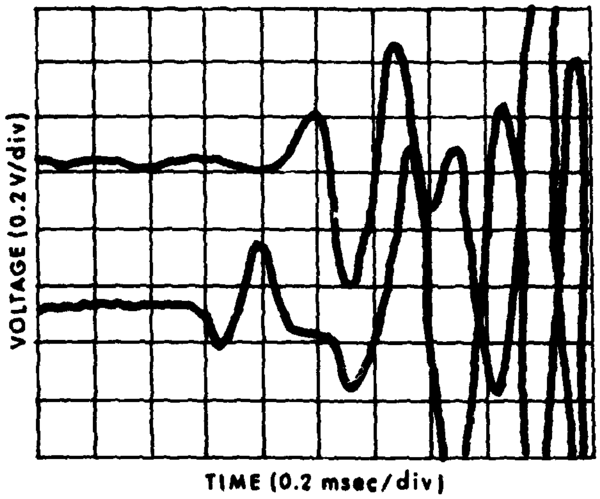

Fig. 7A - Hydrophone 1: 4 ft deep, 6 ft distant

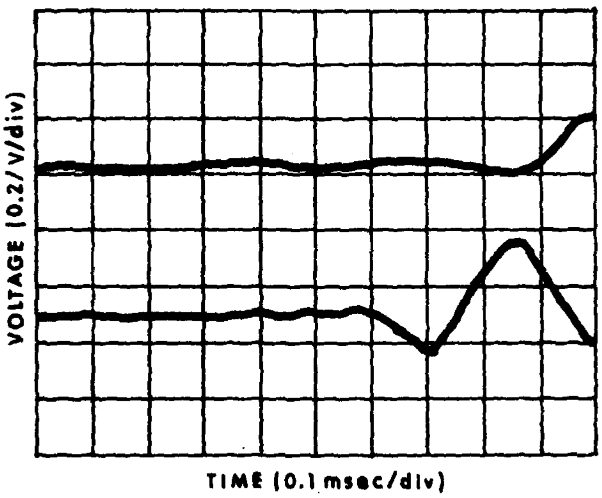

Fig. 7B - Hydrophone 2: 4 ft deep, 12 ft distant

Fig. 7 - Alternate Pinger Signal

Reference bottom water sound speeds were obtained with the sound velocimeter. Before and after each penetration into the sediment the reference velocity and arrival time in water of the pinger signal were used to determine accurately the separations of the probe legs. This calibrated separation distance and the sediment arrival times, as determined by means of the playback system (Fig. 7), were used in calculating an in situ sediment velocity. In addition, these velocities were corrected for geometric variations as the hydrophones moved deeper relative to the constant source depth. Sound velocities across the DOSP sediment core samples were determined onboard ship by using an Underwater Systems Sediment Sound Velocimeter (Model 102 B) and, in the URI Laboratory, under triaxial compression. As shown in Table 3, the variation in the sediment velocities was insignificant.

Table 3
SOUND VELOCITIES

Area	Depth (ft)	Velocity (ft/sec)
Bottom Water	-	5050
In Situ Sediment	4	4950
Shipboard Core Sample	4	4953
Laboratory Core Sample	4	4933

SUMMARY

The Deep Ocean Sediment Probe (DOSP) was built by the Ocean Engineering Department of the University of Rhode Island under contract from the Navy Underwater Sound Laboratory. The DOSP is a satisfactory, versatile platform from which to operate a corer for collecting high-quality samples for engineering and acoustical property analyses and for making in situ measurements with a minimum of disturbance. At present, the active and passive transducer components consist of a spark discharge acoustic source, three hydrophones, and two thermistors. Its size and weight permit operation from the larger deep research vehicles (DRV's), and from almost any size surface research vessel. It was originally designed for immediate use on a DRV, but funding and certification restrictions within the Department of the Navy preclude the prospects for near future DRV utilization.

Initial at-sea tests conducted in shallow water from an AGOR vessel produced favorable results. Immediate modifications that are being considered to effect deep water surface vessel operations involve (1) the replacement of ac motors with dc motors and power pack on the DOSP in order to solve the problem of ac power losses due to long lengths of cable and (2) the addition of an FM multiplex telemetry system to reduce the number of electrical conductors in the cable.

Plans for the coming year include the following:

a. Optimization of the design of the hydrostatic anchor to provide maximum holding forces for different soil types.

b. Fabrication of inexpensive dc reversible, submersible motors.

c. Construction of a compatible telemetry system.

d. Investigation of methods for increasing bottom penetration.

e. Incorporation of a gamma-aborption sediment density probe.

f. Continuation of the core sample disturbance analysis.

The proposed development plan for the next 3 years calls for incorporating an electrical resistivity sensor with an associated geochemistry package, shear wave measurements, shear strength measurements, and a multiple corer capability. At present, the expected maximum penetration may be about 30 ft and would be influenced primarily by shipboard handling limitations.

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13. ABSTRACT

A hydrostatically anchored four-probe assembly with a centrally located slow-penetrating corer measures the thermal and acoustic properties of sediments during incremental penetrations to 5 ft in water depths to 5000 ft. This deep ocean sediment probe can function from submersibles or surface vessels.

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